International Journal of Solids and Structures 48 (2011) 1130–1140

Contents lists available at ScienceDirect

International Journal of Solids and Structures

journal homepage: www.elsevier.com/locate/ijsolstr

Effects of humidity and temperature on subcritical crack growth in sandstone

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ARTICLE INFO

Article history:
Received 26 May 2010
Received in revised form 9 November 2010
Available online 30 December 2010

Keywords:
Subcritical crack growth
Sandstone
Double Torsion method
Temperature
Relative humidity
Clay

ABSTRACT

In order to ensure long-term stability of structures in a rock mass, the study of time-dependent fracturing is essential. The influences of the surrounding environmental conditions and rock fabric on subcritical crack growth in sedimentary rocks in air are yet to be clarified, while the nature of subcritical crack growth in igneous rocks has been studied well. In this study, the influences of temperature and relative humidity on subcritical crack growth in Berea sandstone, Shirahama sandstone and Kushiro sandstone were investigated in air. The load relaxation method of Double Torsion (DT) testing method was used to measure both crack velocity and stress intensity factor under a controlled temperature and relative humidity.

Results show that the change of the crack velocity at a given stress intensity factor was unclear when the temperature increased under a constant relative humidity in air. On the other hand, we show that the crack velocity increased by several orders of magnitude when the relative humidity increased threefold or fourfold under a constant temperature at a given stress intensity factor. This increase is much larger than that expected from the conventional concept based on the theory of stress corrosion. It is therefore necessary to consider the additional mechanisms for subcritical crack growth in sandstone. The increase of the crack velocity was larger for sandstone which contained larger amount of clays. We conclude that subcritical crack growth in sandstone in air is affected remarkably by the relative humidity and the amount of clays in rock.

1. Introduction

Long-term stability of the rock mass surrounding structures, such as repositories of radioactive wastes in underground, caverns to store liquid natural gas (LNG) or liquid petroleum gas (LPG), or underground power plants is paramount. For this purpose, it is necessary to estimate the long-term strength and time-to-failure of rock. To this end, a number of investigations have been conducted (Schmidtke and Lajtai, 1986; Wilkins, 1987; Jeong et al., 2007; Nara et al., 2010a). Additionally, it is considered that time-dependent fracturing of rock is related to the increase of seismicity seen prior to earthquake rupture and volcanic eruption (Kilburn and Voight, 1998). Therefore, study of subcritical crack growth is also important for seismology and volcanology. Chau and Shao (2006) reported that time-dependent crack growth in rock played an important role for the failure of rock panels on façade of buildings. It is considered that study of time-dependent crack growth in rock is essential to understand the failure of most structures made of rock.

Although the classical fracture mechanics has postulated that a crack propagates when the stress intensity factor reaches a critical value (fracture toughness), a crack can propagate even when the stress intensity factor below the fracture toughness of the material. This phenomenon is called subcritical crack growth (Atkinson, 1982, 1984; Atkinson and Meredith, 1987), one of the main mechanisms of time-dependent deformation in materials (Dascalu et al., 2010). To better understand the time-dependent behaviour of rock, a lot of studies of subcritical crack growth have been conducted especially in igneous rocks. It has long been known that subcritical crack growth in igneous rocks is affected by fabric of rock and surrounding environmental conditions.

For granite, Sano and Kudo (1992) reported that the crack velocity was anisotropic and affected by the preferred orientation of pre-existing microcracks. Nara and Kaneko (2006) reported that the anisotropy of the crack velocity in granite was decided by the crack propagation direction. According to Nara and Kaneko (2006), when the crack propagated parallel to Rift plane, along which the most pre-existing microcracks are distributed, the crack velocity was the highest. Nara et al. (2006) concluded that the crack propagated by connecting to microcracks ahead of the crack

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0020-7683/$ - see front matter
doi:10.1016/j.ijsolstr.2010.12.019